

DEPARTMENT OF COMMERCE AND LABOR

TECHNOLOGIC PAPERS
OF THE
BUREAU OF STANDARDS

S. W. STRATTON, DIRECTOR

No. 14

**LEGAL SPECIFICATIONS FOR
ILLUMINATING GAS**

BY

E. B. ROSA, Chief Physicist, and
R. S. McBRIDE, Assistant Chemist
Bureau of Standards

[JANUARY 10, 1913]



WASHINGTON
GOVERNMENT PRINTING OFFICE

1913

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LEGAL SPECIFICATIONS FOR ILLUMINATING GAS¹

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CONTENTS

	Page.
Introduction.....	3
1. Function of a gas ordinance.....	4
2. Previous recommendations.....	5
3. Candlepower <i>v.</i> heating-value regulations.....	6
4. Net and total heating-value standards.....	9
5. Net heating value as a standard.....	12
6. Total heating value as a standard.....	16
7. Net or total—Which shall be used as a standard?.....	18
8. Minimum values and monthly averages.....	20
9. Standard conditions for gas measurement.....	21
10. Reduction of candlepower measurements.....	24
11. Candlepower test burner.....	28
12. Sulphur, ammonia, and hydrogen sulphide.....	28
13. Composition of gas.....	30
14. Pressure of gas.....	30
15. Meter testing requirements.....	30

INTRODUCTION

At the suggestion of certain members of this institute, the Bureau of Standards undertook several years ago an investigation of calorimetric standards and of flame standards for gas photometry. As the work progressed it became evident that other phases of gas testing were equally deserving of attention, and the field of the investigation was, therefore, extended to include all gas-testing work.

As a large part of such testing work is done for the enforcement of gas regulations and for works control to meet the provisions of law, a study of the laws under which this work is done was an

¹ Written for the Seventh Annual Meeting of the American Gas Institute, and slightly revised for publication as a technologic paper of the Bureau.

essential part of the problem. The first results of this portion of the work were published last April as Bureau Circular No. 32, entitled "State and municipal regulations for the quality, distribution and testing of illuminating gas." A review of this phase of the question is the subject which your technical committee have asked the Bureau to present at this meeting, including a discussion of some contemplated changes. The opportunity to do this is appreciated, as it permits a statement of the method of our work and the spirit and attitude of the Bureau in the investigation.

1. FUNCTION OF A GAS ORDINANCE

Since one of the chief features of a gas ordinance is a specification of gas quality upon which the sale to customers is to be made, it must of necessity involve the question of the price of the gas to the purchaser. Although the Bureau of Standards has not undertaken an investigation of the price of gas, the fact has been borne in mind that all regulations which are adopted must be carefully considered from the standpoint of their probable effect upon the cost and the selling price of gas. Indeed, the question of the quality of gas which is to be prescribed is one which has necessitated study not only from the scientific and technical standpoint, but also from the economic side. The Bureau has endeavored to study and treat it broadly from these various points of view, and in all phases of the problem has striven to give careful and unbiased consideration to all of the facts which bear upon each question investigated, in order to reach correct and just conclusions.

As a regulatory gas ordinance is really a specification accompanying the contract between the gas company and the public, it should clearly define the quality of the gas and gas service which it is expected that the company will furnish to its customers. The standards set by the law should be such that they define without ambiguity those qualities of the gas and gas service which determine the usefulness of the gas to the purchaser. Furthermore, the law or rules should be sufficiently comprehensive to cover all of those points on which the public can reasonably ask assurance as to the quality of the gas or the service to be

rendered. Because a company is likely without regulation to fulfill certain important conditions is not sufficient reason for the omission of these conditions from the legal specifications.

It is obviously not possible to lay down rules which will apply alike to all cities and towns in which gas is supplied, but it has been found by the Bureau that a greater uniformity of regulation could be adopted to advantage, and a discussion of the fundamental principles upon which regulatory rules should be based has been one of the objects of our publication.

In the recommendations which have been made by the Bureau the fundamental idea has been to set forth clearly a review of those subjects which are necessarily covered in a regulatory gas ordinance or law. It is hoped that such an impartial presentation of the subject will enable city and State legislators to understand more quickly and more thoroughly the technical questions involved and assist them in the enactment of laws which will better accomplish their purpose.

2. PREVIOUS RECOMMENDATIONS

It is expected that Circular No. 32 will be revised and a second edition published during the present year. In this revision will appear certain changes in the recommendations of the first edition, with which many of you are more or less familiar. Some of the changes under consideration are discussed in this paper. The general provisions recommended by the first edition were as follows:

A double standard has not been recommended for municipal gas control except for large cities, and when only one is required no definite expression of preference as to candlepower or heating-value rules has been given. When a lighting-value regulation is desired, a candlepower of 15 for coal gas and 18 for water gas is recommended, using for the testing an open-flame burner, an open-bar photometer, and a 10-candlepower pentane lamp as standard; but when used with a heating-value requirement, only a 15-candlepower requirement appears necessary, even for water gas. A standard heating value of 600 Btu gross per cubic foot of gas was proposed for all kinds of gas. Both heating value and

candlepower requirements are on monthly averages, deficiency of 2 candlepower or 50 Btu on any day being allowed without penalty.

The purity requirements proposed follow the usual lines in prohibiting the presence of hydrogen sulphide, as judged by a rather lenient method of test, which is specified; and the ammonia and total sulphur are limited to 5 and 20 grains per 100 cubic feet, respectively, for water gas, or 10 and 30 grains for coal gas.

The limits fixed for pressure are 2 and 6 inches, but the maximum on any day must not be greater than twice the minimum on the same day, as measured at any one service outlet. However, penalty for pressure deficiency is not imposed, except when less than 1.5-inch pressures are found, although less than 2-inch pressures must be corrected within reasonable time. No opinion is expressed on meter testing as to who should be responsible for this work, but provisions for testing all meters once in five years are recommended.

State regulations are different in form, but their technical features are very similar to those proposed for cities.

As was suggested in Circular No. 32, State regulations should not be fixed in a general law, but rather by the State commission operating under a law which gives it the necessary authority; for the same requirements can not always be fairly made of every company, and under special conditions it may be desirable to depart rather widely from usual values.

Having in mind these general rules which were given in Circular No. 32, let us consider the basis upon which they are laid and the desirability of certain changes.

3. CANDLEPOWER v. HEATING VALUE REGULATIONS

It is commonly believed that the heating value of a gas is a better measure of the general usefulness of the gas than is the candlepower, and for most places there is no doubt that the heating value standard is preferable to candlepower regulation when only one of them is used. The objection to the heating-value requirement that it requires some experience to be able to make gas to

such a standard with a maximum efficiency does not appear to be serious. It is evident that a gas maker can not from the first be expected to make gas with the greatest possible efficiency under new conditions, but the experience of those who have made a fair trial of the methods for works operating on a heating-value standard indicates that greater economies of operation can be obtained as the details of the new methods are developed. Another practical advantage to the manufacturer is that the losses of heating value of the gas during distribution are much less proportionately than are the losses of candlepower; and, further, abnormal weather conditions are less troublesome when control is on a heating-value basis. It seems certain, therefore, that even from the first a great economy will result under heating-value standards as at present, and that increased experience will permit appreciable improvements over present conditions.

From the point of view of the usefulness of the gas to the customer, there is no doubt that both the heating and the lighting value of the gas should be maintained above certain minimum values. However, some engineers claim that a company should not be required to maintain both candlepower and heating value of specified amount, as they believe that under the present methods of manufacture and with the present-day appliances for gas consumption it is only necessary to regulate one of these qualities and allow the other to be what will correspond, having regard only for economy of manufacture.

At the present time the methods employed in gas making are such that all coal and water gas made on a heating-value basis will also have a reasonable candlepower; but gases of nearly normal-heat value and very low candlepower are available, and whenever it is found practicable to supply these gases at a satisfactory price the question arises as to how far we may disregard the lighting value of the gas. There are those who say that if gas can be made cheaper by this procedure it is proper even at the present time to wholly disregard the open-flame candlepower of the gas. However, the Bureau has taken the attitude that there are still too many who are utilizing gas in open-flame burners to do this.

There is some question as to how far the change from open-flame to mantle lights can be carried, as there are places for which the open-flame burner is better suited than is the mantle light. These places are basements, halls, storage and attic rooms where the light is little used or where the burner is subject to such rough treatment as to make a mantle impracticable. In combination fixtures, where gas is used only in case of interruption of the electric service, the extra investment in mantle lights is not warranted, even if the mantle burner were adapted for use on combination fixtures, which is usually not the case.

A nominal candlepower gas will be sufficient for use in such places as those just mentioned, and without legal candlepower regulation the gas made by the ordinary processes of the present day will be satisfactory in quality for emergency use in fixtures, even if only heat value is controlled, since the lowest candlepower would scarcely be less than 10 candles if the gas were of 600 Btu or higher. On the other hand, it is uncertain what would be the result if a gas maker undertook to wash the gas with oil or to make considerable modifications in the retort or generator operation. We have not yet reached the time when customers requiring open-flame candlepower in gas are negligible numerically; nor has it yet been proved that the manufacture of a nonluminous gas is most economical or desirable. We are therefore disposed to recommend retaining a minimum candlepower requirement as a secondary standard in addition to the more important heating-value standard. Such a minimum candlepower value should be low enough so that the manufacture of gas is not thereby complicated and its cost is not increased. No penalty need be imposed for daily deficiency in candlepower under these rules and possibly a slight deficiency in a single monthly average might be allowed without penalty if subsequent averages were above the requirement.

Whenever such methods of operation are devised that the methane content of the gas can be largely increased, we shall be confronted with this problem; and it is not improbable that such process will be devised in the near future. If the time comes when a nearly nonluminous gas is clearly to the advantage

of the public, the price would probably have to be readjusted, and in that case the candlepower requirement can be readjusted also.

The use of a minimum candlepower requirement, as described above (say 12 to 15 candles measured in an open-flame burner), is not what we understand by a double standard. The latter involves a candlepower requirement as difficult to meet as the heating-value requirement, so that the company would find it necessary to watch both calorimetric and photometric values daily. This we do not recommend.

Gas can be too rich in illuminants for the best service with mantles, as well as too poor for satisfactory service with open flames. Too high or too low a heating value will be less economical than some intermediate value. A wisely chosen mean, to be clearly specified and carefully maintained, is what is wanted; but this best mean is not everywhere the same, and under special conditions it may be desirable to depart rather widely from usual values. Hence, the State commissions should be authorized to fix the values required and to make exceptions for special reasons.

4. NET AND TOTAL HEATING-VALUE STANDARDS

Definitions.—For a clear understanding of the relative merits of the net and total heating values of gas as standards of specification it is necessary to define these terms accurately. The gross heating value and total heating value are often used synonymously; however, if we define the latter precisely, we find it useful to distinguish between it and the uncorrected measured value, commonly called the gross value.

Let us consider what takes place in a calorimeter.² Entering the instrument there is, first, gas at room temperature saturated with water by passing through the wet meter by which it is measured; and second, air at room temperature and room humidity, in quantity determined by the form and the method of operation of the instrument. The gas is burned, forming water and carbon dioxide, with liberation of heat, and the products of combustion are cooled by the water flowing through the calori-

² The term "calorimeter," as here and subsequently used, refers to a water-flow calorimeter unless otherwise stated.

meter practically to the temperature of the inlet water. During the cooling part of the water vapor is condensed to liquid, and the products of combustion escape, carrying enough water to saturate them at the exhaust temperature. The amount of water condensed is equal to the amount formed in the flame only when the water vapor entering with gas and air equals the water vapor leaving in the products of combustion. If, as usually is the case, less water enters as vapor than leaves in the products, obviously the amount of water condensed is less than that formed in the flame, and vice versa. In extreme cases the water required to saturate the products of combustion may be as much as that which enters, plus that which is formed by burning the gas; there is then no water condensed.

Thus the heat to be measured by the calorimeter due to combustion in the flame is made up of two parts:

First. The heat given up by radiation from the flame and by *cooling* the products of combustion to the exhaust temperature.

Second. The heat given up by *condensing* water from vapor to the liquid condition.

If an efficient calorimeter is properly operated, practically all of the sensible heat that can be obtained by cooling the products to room temperature is measured, together with the heat of condensation of that amount of water which can be condensed under the existing atmospheric conditions. This heat is that ordinarily measured by a calorimeter and is often called the gross heat; however, we shall hereafter call it the observed heating value and we shall use the word "gross" as synonymous with total. From the heat measured by the calorimeter the amount of heat which is liberated by condensing the water from vapor at room temperature to liquid at room temperature can be deducted. The value thus obtained is the heat which would have been measured if all of the water had gone out in the products as vapor. This is known at the *net* heat. On the other hand, if we correct the observed heating value so as to include the heat which is lost or to exclude any that is gained by the fact that the condensed water does not equal that formed in the flame, then the true *total* heat of the gas is obtained.

As the amount of moisture condensed in the calorimeter depends not only upon the quantity produced in the flame by combustion but also depends upon (1) the amount brought in by the incoming air and gas, and (2) the amount carried out by the products of combustion, we see that the portion of the heat of condensation measured is variable, depending upon atmospheric temperature and humidity and upon the quantity of air entering the calorimeter. Therefore, the observed heating value is not a constant depending only on the quality of the gas, like the total and the net, but varies appreciably. In extreme cases it may be as small as the net or as large or larger than the total.

These three heating values of the gas can therefore be defined as follows:

The *observed* heating value of a gas is the heat measured by an efficient calorimeter when a unit volume of gas is burned, the air supporting combustion entering the calorimeter at the temperature and humidity of the room and the products of combustion leaving saturated at about the same temperature.

The *total* heating value of a gas, often called the "gross" heating value, is the total heat liberated by the combustion at constant pressure of a unit volume of that gas with air of the same temperature when *all* of the water formed in the flame (and no more) is condensed and the products of combustion are cooled to the original temperature.

The *net* heating value of a gas is the heat produced by the combustion at constant pressure of a unit volume of that gas with air of the same temperature when none of the water formed in the flame is condensed to liquid, but when all of the products of combustion are cooled to the original temperature.

From the observed heating value, as above defined, we obtain either net or total, the one by a correction depending upon the water condensed in the calorimeter, the other by a correction depending upon atmospheric conditions. It is assumed that this observed value will be free from errors of gas measurement and temperature measurement and from radiation losses which are preventable by proper operation of the calorimeter, or for which suitable small corrections can be made.

5. NET HEATING VALUE AS A STANDARD

Having clearly in mind the relation of the observed, the net, and the total heating values, let us consider their comparative value as a measure of gas quality for purposes of legal specification. The three most important considerations then before us are as follows: First. Which heating value is the best measure of the usefulness of the gas to the consumer? Second. Which value can be controlled by the gas maker most easily and with least expense? Third. Which value can be determined for purposes of control or inspection with greatest ease and exactness?

1. At the present time there are no gas-consuming appliances in general use which utilize more than the net heat of the gas, and there is no probability that any appliances will be built which will do so, unless it becomes commercially practicable for a water heater to deliver the products of combustion at a temperature much lower than is now done. As there must necessarily be some loss of heat in any practical water heater or other gas appliance, 100 per cent efficiency on the basis of the total heat is impossible, and we doubt whether 100 per cent efficiency on the basis of the net heat will ever be surpassed in practice. Room heaters, lighting and cooking appliances, and all power-producing devices deliver the products at relatively high temperature (say, above 150° F.), so that no moisture is condensed inside the appliance, and hence can never use more than the net heat. In order to produce the necessary draft the products from any appliances, even water heaters, must escape into the flues at a temperature considerably above that of the room. The maximum usable heat is, therefore, generally much less than the net heat.

From the above facts it is probable that the maximum efficiency of most appliances will be reached in practice when all of the net heat of the gas is utilized. It thus appears that the net heat most nearly measures the usefulness of the gas to the consumer.

2. In considering which heat value can be best controlled by the gas maker there is no evidence to show that the gas maker can control his generation or purification processes to better advan-

tage on the one basis than upon the other, but there is one factor which may be overlooked in this connection. If to-day a gas is made of exactly the same chemical composition as that made yesterday, the maker would expect that the heating value would be the same. However, if a considerable change in humidity has occurred, the observed heating value of the gas as measured on the second day may be as much as 10 or 15 Btu higher or lower, even assuming that perfectly correct observations be made in the measurement of it. Now, if the value of the gas varies appreciably when on an observed heating-value basis, due to the weather, the gas maker would find exact works control less easy on that account. Although it is not possible to control manufacturing processes perfectly, unnecessary uncertainties should not be encouraged.

3. For the consideration of the relative accuracy of the determination of the three heating values we must again consider the factors which influence each. In the first place we have errors in observation of gas volume, water temperatures, and gas temperature or pressure, all of which errors have the same effect upon each of the three heating values. In this respect they are on a par. The efficiency of the calorimeter as an absorber of the heat also has no influence upon one that is not also true of the other two as well, and the failure properly to cool the products of combustion has an equal influence upon each value as far as it affects the sensible heat in the products of combustion. On the other hand, the amount of water entering and leaving the calorimeter in the vapor state has a very different effect upon the different values.

The amount of moisture which enters the instrument is determined by the amount of the air entering and its moisture content; and the amount of water leaving as vapor is determined by the quantity of the products of combustion and their temperature of saturation. For a correct determination of the total heat it is necessary that all of the water formed by the burning of the gas be condensed in the calorimeter and that all other water entering the instrument be discharged as vapor. To produce this condi-

tion it is evident that the water entering in the gas and air as vapor must be adjusted so that its amount is equal to that in the products of combustion; and furthermore, as the products always leave the calorimeter saturated with water vapor at their outgoing temperature, it is necessary that the air and gas entering the calorimeter bring in just enough water to accomplish this saturation of the products. Now, this adjustment is obviously one which can not be exactly made unless the water vapor content and the quantity of the air entering be known. From a practical standpoint, there is no convenient way by which the water entering the instrument can always be made equal to the amount leaving the instrument. The problem has become one of adjusting the conditions of the test so that the difference shall always be a minimum.

To illustrate the problem by an example, we will take a gas of total heating value of 600 Btu per cubic foot and of net heating value of 550 Btu per cubic foot. If this gas is burned in a calorimeter with about six volumes of air which is 90 per cent saturated with moisture and at 70°, we would find the following conditions to hold:

	Grams.
Water entering with 1 cubic foot of gas (being saturated by passage through the wet meter at 70°)	0. 5
Water entering with 6 volumes of 90 per cent saturated air at 70°	2. 7
Water formed by combustion (equivalent to 50 Btu difference between total and net as assumed above)	21. 7
Total entering and formed	24. 9
Water leaving in products of combustion ³	2. 75
Difference or water condensed in the calorimeter	22. 15

Under the conditions assumed for this test more water is condensed in the calorimeter than is formed in the flame; the heat of condensation of this excess being measured, the observed value will be higher than the total by the amount equivalent to this excess of condensed water, or 1 Btu above the total value.

³The products of combustion are assumed to be at the room temperature and saturated at this temperature. Their volume is in all cases of coal, water, or mixed gas practically equal to the volume of the air entering less one-half of the volume of gas entering. The contraction is due to the condensation of the water formed in the flame. To calculate the water in the products, the following method is employed: Multiply the volume of air less one-half the volume of gas by the amount of water required to saturate one volume of products at the temperature of the exhaust.

Use has been made here of both metric and English units to correspond with usual gas laboratory practice, although rather an unscientific combination results.

If under other conditions of test 9 volumes of air were passed for each volume of gas burned and the room was at 80° and the air 30 per cent saturated, we should find an observed value of only 592 Btu, or 8 Btu below the total. Considering the conditions which exist in the laboratories of this country, it is evident that there would be variations (apart from errors of observation) such that gas of 600 Btu total heating value would show from 605 Btu to 585 Btu or less.

On the other hand, when the net value of the gas is measured there is no need to consider the influence of humidity or quantity of air flowing through the calorimeter. If, as in the examples given above, the condensed water were too great or too small, the water corrected for in determining the net would be correspondingly larger or smaller. The net value resulting is, therefore, in each case automatically corrected to its true amount, every increase in observed value being counterbalanced by increase in the correction for getting the net value and vice versa.⁴ The following conditions affect the observed value even when the calorimeter is correctly operated, but do not affect the net value: (1) Humidity of room, (2) room temperature, (3) rate of gas consumption, (4) position of damper, and temperature of exhaust (this last does affect the net slightly, but much less than the observed).

The only measurement required for determination of the net not also required for the observed is the measurement of the quantity of water condensed during the burning of a cubic foot of gas. This observation is easily made with such exactness that no errors greater than 2 Btu (equivalent to 1 cc of drip per cubic foot of gas burned) are to be expected.

It is possible that leaks from the water-circulation chambers into the flues of the calorimeter would occur and render the drip collected too great in amount. One or two inspectors have noted such leaks, but the majority of calorimeter users seem to have experienced no difficulty in this way. If they occur, such leaks would render net values incorrect but would affect the observed

⁴This fact has been overlooked by most authors of calorimetric discussions; it was known to Coste, among others, and emphasized by him at least two years ago. (See p. 49, *The Calorific Power of Gas*, by J. H. Coste, 1911.)

values only slightly. Apparently this error need not be considered as a serious factor, except possibly in traveling colorimetric work for State inspection; and here a simple test will show whether the calorimeter leaks.

6. TOTAL HEATING VALUE AS A STANDARD

In the rules adopted by the 4 State commissions which have made heating-value regulations, the requirement is made that the "total heating value" be above a specified standard; however, in the 30 or more cities having heating-value limits in ordinances, we have found no city which specifies the total heating value. Nineteen of these 30 cities do not state precisely what is intended, 8 specify "gross" value, 2 require "net," and 1 states the requirement in terms of "low value," probably meaning net.

In laboratory methods and in technical discussions the observed value as measured is generally used, and in endeavoring to get the highest value possible, the so-called "maximum efficiency," the calorimeters have been so operated that the measured value has usually come very near, indeed, to the total. Moreover, by the application of a small correction, which can be taken from a table of corrections when we know the atmospheric humidity and the room temperature, it is practicable to correct this measured value to the total. In routine testing under average conditions this correction may be ignored, but under unusual conditions or when accurate results are desired it can easily be applied. The magnitude of this correction will, of course, depend upon the quantity of air passing through the calorimeter, but if a calorimeter has been calibrated and is used in the manner prescribed, there will be so little variation in the quantity of air that the uncertainty in the correction will be negligible. At the worst it will be much less uncertain than the uncorrected value.

One method for the direct determination of the total heating value has been suggested, namely, to vary the temperature of the ingoing water so that the products of combustion will escape at such a temperature that the quantity of water vapor carried out of the calorimeter shall be equal to that entering, and thus the heat measured will equal the total. This procedure, of course,

requires a knowledge of the atmospheric humidity. Unless the gain in heat from the room were taken into account, which was not suggested in the above proposition, the error introduced might be as great as the one to be corrected, for at best it amounts to making the necessary correction in a somewhat clumsy way by experiment, instead of taking it from a table of corrections and adding it to the measured value.

If, therefore, the total be used as the standard value for testing purposes, we recommend the use of a table of corrections, such as given on page 18. Owing to the water carried into the calorimeter with the gas and the contraction of the total volume due to combustion, the entering air should not be saturated, if 7 volumes of air are used and the air enters at 80 per cent relative humidity and leaves at 100 per cent the water condensed will be exactly equal to the water formed in the flame. In other words, 80 per cent humidity will be a standard atmospheric condition requiring no correction for the total; the table will then give the correction for the difference between the actual relative humidity and 80 per cent. At 10 per cent humidity, such as often occurs indoors in winter weather, the correction to be added to the measured value varies from 4.8 Btu at 65° to 10.5 Btu at 90°. If the air enters saturated, the small correction is to be subtracted. At nine volumes of air the correction is larger.

On the other hand, if the heating value is measured by a bomb calorimeter or by one of the Parr type, the total heating value is observed directly, there being no correction necessary for the loss or gain of heat of condensation. However, with the bomb calorimeters the heat of combustion at constant volume is measured and this must be corrected to heat at constant pressure. It might also be possible that by the use of an air saturator the total value can be directly measured in a gas calorimeter of the usual Junker's type, but an apparatus for saturating or making the humidity of the air constant has not yet been proved to be a practicable attachment to a calorimeter, nor does it appear desirable to add such accessory since the correction can be made so easily by other means.

TABLE I

Corrections to Observed Heat to get Total Heat Value

Air, gas, and exhaust must be at the same temperature

A. IF 7 VOLUMES OF AIR PER VOLUME OF GAS ARE USED

Per cent humidity.	Corrections at various room temperatures.					
	65°	70°	75°	80°	85°	90°
10	+4.8	+5.7	+6.7	+7.9	+9.2	+10.5
20	+4.1	+4.9	+5.7	+6.8	+7.8	+ 9.0
30	+3.4	+4.1	+4.7	+5.6	+6.5	+ 7.4
40	+2.7	+3.2	+3.7	+4.5	+5.2	+ 5.9
50	+2.0	+2.4	+2.8	+3.4	+3.8	+ 4.3
60	+1.3	+1.6	+1.8	+2.2	+2.5	+ 2.8
70	+0.6	+0.8	+0.8	+1.0	+1.2	+ 1.2
80	-0.1	±0.0	-0.1	-0.1	-0.1	- 0.3
90	-0.8	-0.9	-1.1	-1.3	-1.5	- 1.9
100	-1.6	-1.8	-2.0	-2.4	-2.8	- 3.4

B. IF 9 VOLUMES OF AIR PER VOLUME OF GAS ARE USED

10	+6.7	+7.9	+9.2	+10.8	+12.5	+14.5
20	+5.8	+6.8	+8.0	+ 9.3	+10.8	+12.5
30	+4.9	+5.7	+6.8	+ 7.8	+ 9.1	+10.5
40	+3.9	+4.7	+5.5	+ 6.4	+ 7.4	+ 8.5
50	+3.0	+3.6	+4.3	+ 4.9	+ 5.7	+ 6.5
60	+2.1	+2.5	+3.0	+ 3.4	+ 4.0	+ 4.5
70	+1.2	+1.4	+1.8	+ 2.0	+ 2.3	+ 2.5
80	+0.2	+0.4	+0.5	+ 0.5	+ 0.6	+ 0.5
90	-0.7	-0.7	-0.7	- 0.9	- 1.1	- 1.4
100	-1.6	-1.8	-2.0	- 2.4	- 2.8	- 3.4

7. NET OR TOTAL—WHICH SHALL BE USED AS A STANDARD?

Let us briefly restate the merits of these two standards, either of which can be used satisfactorily.

1. The net heat is, on the whole, probably the best measure of the usefulness of the gas to the consumer; it depends only upon the quality of the gas, being unaffected by atmospheric conditions at the time of test and is easily measured experimentally.

2. The total heat is the value specified in four State laws and is the value probably intended in all other laws which say "gross" value or which do not specify which standard is meant. It is

apparently the value which has been sought for in defining conditions of testing, and where "gross" is used in practice it is usually taken to be synonymous with total. The total heat depends only upon the character of the gas and can be obtained from the measured value by the use of a simple correction. For ordinary work the observed heat value of coal gas, water gas, or mixed gas is within 2 per cent of the total value; and unless greater accuracy than this is desired no correction to the results of the regular test is required. When the small discrepancies of observed values are of importance, they can be eliminated without difficulty by correction to the total, using a tabular correction as given in Table I.

The examination of the records for a large number of cities scattered over the country shows that the mean atmospheric condition is probably represented by 40 per cent relative humidity at 70° F, the air then carrying 1 per cent by volume of water vapor. Hence if we correct the measured heat by means of a table to the total heating value, we can obtain a value which would be higher than that obtained at the mean humidity.

To use such a value does away with the fluctuations, which under unusual conditions are important, but gives a value which will not be in exact agreement with the mean of a large number of determinations made under a great variety of atmospheric conditions. In other words, if this procedure is adopted, the present name gross or total will be continued, but the present mean value of the standard will be slightly changed. It is in effect a lowering of the standard by about 3 Btu, a change which might be objected to on principle, even though it is small.

This change, however, is smaller than the change which will result in the heating value effectively required if certain changes in the operation of the Junkers type of calorimeter proposed by Messrs. Waidner and Mueller be adopted. In their very thorough study of gas calorimeters at the Bureau of Standards these investigators have found that the effect of stem corrections of the thermometer readings and radiation losses not heretofore taken account of in gas calorimetry have caused the measured-heat values to be from 2 to 3 per cent too low (10 to 20 Btu). In order to make

calorimetric measurements correct, these sources of error should be eliminated and the gas given its true value.

The effect of so doing, however, will be to make existing standards less severe by 10 to 20 Btu. Whenever a heating value is being adopted for the first time, or when the price of gas is being readjusted, this change will, of course, be taken into account. But where a heating value is now required by law there may be a question as to whether the same numerical value is to be required, or such a value as to provide an equal quality of gas. Fortunately, in most cases the companies are now furnishing a little better than the minimum requirement, so that this question will not in practice be as acute as otherwise.

The 2 or 3 per cent variation just mentioned, which will favor the gas companies, will be needed in some cities to counterbalance the effect of reduced barometric pressure which will be discussed presently.

If it be objected that to apply these corrections in order to obtain the heating value of the gas more accurately will make the calorimetry of gas much more difficult, the answer is that anyone who is competent to conduct the experimental part of the work and obtain satisfactorily the uncorrected gross, is also competent to apply the corrections; for they will be taken from simple tables of corrections prepared for general use, and the process will be a routine one after the observations are completed.

8. MINIMUM VALUES AND MONTHLY AVERAGES

For purpose of official specification the monthly average heating value and monthly average candlepower of the gas have been recommended by the Bureau. The use of monthly averages has been practiced for some time in the case of heat value, but as far as we can learn no city or State had adopted a monthly average candlepower before the time when this was recommended by the Bureau. The advantage of averages as a basis for specification is obvious to all who know of the difficulties in making an exactly uniform product. The disadvantage to the user of gas has not always been so clearly recognized. The gas which from day to day or from hour to hour has the least variation in candlepower,

heating value, density, and, most important of all, pressure, is the gas which gives to the consumer the most satisfactory service. Large variations in quality, density, and pressure are certain to render unsatisfactory a gas which on an average may be very good in quality or pressure. Minimum allowable values for any one day must therefore be specified.

The allowance of a deficiency of two candles in the candlepower of any one day is not unreasonable if the gas maker does not attempt to take undue advantage of this tolerance, which is intended to provide for unusual conditions of weather or accidents beyond the control of the company. It is expected that reasonable efforts will be made to keep the gas up to the average value required.

At the present time it is customary to allow a deficiency of 50 Btu in the heating value on any single day below the standard specified. This allowance is probably too great for the best service, as such irregularities as may thereby result do not permit the most satisfactory utilization of the gas. It is expected that after a few years more of experience in making gas on a heat-unit basis, makers will be able to secure greater uniformity, but for a while it seems best to permit an ample tolerance. Whether a closer legal restriction will be found necessary is uncertain; for without legal restriction the gas maker will naturally endeavor to maintain the most uniform gas possible, since this contributes not only to better service, but also to greater economy in manufacturing.

9. STANDARD CONDITIONS FOR GAS MEASUREMENT

In the first edition of Circular No. 32 a cubic foot of gas was defined as follows:

Unless otherwise provided a cubic foot of gas shall mean that amount of gas which occupies the volume of one cubic foot under the pressure of thirty inches of mercury and at the temperature of sixty degrees Fahrenheit when saturated with water.

This definition follows the usual practice in correcting all gas volumes measured in connection with testing to sea-level conditions,⁵ but for purposes of gas specifications it is not in all respects satisfactory.

⁵ The usual scientific standard is, however, 760 mm of mercury pressure and zero degrees Centigrade.

In the specification of a product to be delivered under contract it is customary to state the minimum quality and the exact quantity of the product to be delivered. In the case of gas the purchaser is concerned with the average and the minimum quality of gas delivered to him and its quantity, and there is no need for him to know what would be the quality and quantity if he were living at a lower altitude or in a colder climate. When he pays \$1 for 1000 cubic feet of gas, as registered by his meter, he is interested in the number of heat units received for the dollar, and the gas ordinance should be so drawn as to show this as nearly as practicable. The number of heat units contained in the gas depends, of course, upon its quantity and quality—that is, upon the mass of gas contained in a cubic foot—and its chemical composition. If the meter is correct, it depends, therefore, on the density of the gas and its composition, and as the density of the gas varies with the temperature and pressure (as well as with its composition) we see that temperature, pressure, and chemical composition are the three factors which determine the heating value of the gas. Instead of determining the quality of the gas by means of a chemical analysis, however, the heating value is determined by means of a gas calorimeter; and as the heating value is measured under conditions similar to those under which the gas is burned by gas consumers—that is to say, under the prevailing barometric pressure and at ordinary temperature—there is no need for measuring either the temperature or the pressure, or of applying any correction for either, if they are the same as the mean temperature and pressure of the gas as it is delivered and metered.

There is, of course, considerable variation in the temperature of the meters of a city at any given time, but it is not practicable to measure the temperature of each meter, nor to determine the actual average of all. Hence, in the past and for the future until something better is possible, a standard temperature of 60° F is assumed to be the average temperature, and if the gas passes through the test meter when calorimetric or photometric measurements are being made at a temperature different from 60°, it is

proper that correction be made to this temperature as is ordinarily done.

With respect to the other factor affecting the density of the gas, namely, the pressure, there are three important differences from the question of temperature. In the first place, the barometric pressure is substantially the same everywhere, both indoors and out-of-doors, in a given city at a given time. In the second place, unlike the temperature, its mean value in a given place is or may be very accurately known. In the third place, there is a far greater effect due to variation from the mean of the average pressure in different cities than due to the variation of the average temperature from 60°. The Weather Bureau has published the annual and monthly averages for so many places and the variation due to altitude is so well known that it is a very simple matter to ascertain the average barometric pressure for any place whatever. It is, therefore, neither necessary nor proper to assume that the pressure of the gas in the meters is everywhere the same, as is done for meter temperatures, but the just and proper method is to take as the normal pressure at any given place the actual average barometric pressure of that place. For example, suppose that the ordinance of a particular city states that in all measurements of gas in connection with either colorimetric or photometric testing, correction shall be made to 60° F and 29 inches of mercury (supposing the latter to be the actual average barometer pressure). All calculations are made just as easily as to 30 inches, and the result is correct and just. Therefore the ordinance definition may be as follows:

“For purposes of testing the quality of gas, as provided for herein, a cubic foot of gas shall mean that amount of gas which occupies the volume of one cubic foot at sixty degrees Fahrenheit when saturated with water at this temperature and under a pressure of ——— inches of mercury, which is taken as the mean barometric pressure of this city.”

The readings of station meters, as well as customers' meters, would require no correction for barometer, either in determining the gas unaccounted for or in comparing the results of operation of two different cities; for if gas is measured in the station meters,

the test meters and the customers' meters in cubic feet at the prevailing barometric pressure, all results are comparable (in any one city and between different cities) without taking account of the height of the barometer.

As measured for testing by a wet meter, the gas is practically saturated with water at the temperature of the experimental meter, and in the reduction of the measured volume to 60° F it is customary to correct for the difference in the amount of water in the gas saturated at test meter temperature from that required to saturate the gas at 60° F. This correction is included in the tabular number, as given by most texts on calorimetry or photometry, so that with the correction which is ordinarily made we have the volume corrected for differences in humidity.

The gas delivered to consumers varies in moisture content, being saturated with water at the lowest temperature to which it has been brought during its travel through the mains. If we assume that on an average through the year this lowest temperature is 60° F, then the gas will average about $1\frac{3}{4}$ per cent by volume of water vapor, and it is proper to correct the gas tested to the same condition. Even if the average minimum temperature of exposure of the gas was 50° F, the water content would average $1\frac{1}{4}$ per cent by volume, and it is therefore evident that the rating of the gas at 60° saturation makes only 3 Btu difference from the rating at a 10-degree lower saturation temperature. On the same basis that we accept the 60° F as average meter temperature for all places we assume the same water content for the standard condition in all. Indeed, variations from the average are of very little importance as affecting the gas rating.

10. REDUCTION OF CANDLEPOWER MEASUREMENTS

The taking of gas candlepower according to the present procedure consists in the comparison of the light from a gas flame burning approximately 5 cubic feet of gas per hour with the light from a standard flame, the value of which is fixed for some standard condition of barometer and humidity. This method assumes that the percentage effect of those atmospheric conditions upon the two

flames is the same, and for want of exact knowledge on this subject this assumption is necessary.

Pentane lamps are standardized at the Bureau of Standards by comparison with incandescent electric standards and rated in international candles at a normal humidity of 8 liters of water vapor per cubic meter and 76 cm of mercury barometric pressure. They are used in testing gas at various barometric pressures and humidities, always, however, so far as we know, using in the calculation of results their standard sea-level candlepower. If, however, the humidity is higher or the barometric pressure lower than normal, the candlepower of the standard pentane lamp will be less than its certified value.

So far as the variation of humidity is concerned this practice is rational and satisfactory. The gas company is not responsible for the variation in the humidity and does not profit or lose by it in the long run when gas is tested in this way. The candlepower of the standard will be higher when the humidity is less and lower when the humidity is greater, and, on an average, can not be far from the normal value given for 8 liters of water vapor per cubic meter.

In the same way, fluctuations of the barometer, associated with changes in the weather, cause the light given by the pentane lamp to fluctuate, but these fluctuations cancel out on the average, if the average value of the barometric pressure be used. If, however, the value of the candlepower at 76 cm of mercury is always used when the average barometer is appreciably lower than this, there will be a constant error introduced, corresponding to this constant difference in the barometer. For example, at any place where the mean barometer is 24.72 inches the corresponding candlepower of a pentane lamp having a value of 10 candles at sea level is 8.67 candles.⁶

If, therefore, a pentane lamp, giving on the average 8.67 candles, is taken as 10 candles, the gas is overrated in proportion; that is, about 15 per cent.

⁶ This value is taken from the paper by Butterfield, Haldane, and Trotter; *Journal of Gas Lighting*, 115, p. 288; 1911.

In addition to this overrating, however, it is customary to introduce an additional correction, due to the fact that gas at the higher altitude has a lesser density than at sea level, and the measured candlepower is multiplied by the ratio of the normal barometer to the local barometer, i. e., in this case the measured candlepower is multiplied by the fraction $\frac{30}{24.72}$. For example, suppose that in testing the gas in such city against a pentane lamp with the flame burning at the rate of 5 cubic feet per hour, we find it to have a candlepower $1\frac{1}{2}$ times as great as the pentane lamp. Rating the latter as 10 candles, the gas will be said to have a candlepower of 15 candles. Introducing the correction for pressure by multiplying 15 by the fraction $\frac{30}{24.72}$, we have 18.2 candles as the value which would be assigned to the gas. In reality, however, the flame is giving only 1.5 times 8.67, or 13.0 candles, and reporting it as 18.2, overrates it 5.2 candles. This error of 40 per cent is introduced, first, by assuming the lamp to have a candlepower about 1.3 candles greater than it really has, and second, by introducing a correction which gives the increase in candlepower which the flame would give if it were burned at sea level, assuming that the light would increase in proportion to the increase in the density of the gas. This method is both wrong in theory and misleading in practice. The gas is sold at so much per thousand cubic feet, measured at the prevailing barometric pressure of the city, and its candlepower, which is measured under the same conditions, should be taken as measured, and should not be reduced to sea level nor to any other conditions not realized at that place. In the case of a city which is 1000 feet above sea level, the mean barometer is 28.82 inches, and the error introduced in the testing of gas in this way is more than 6 per cent (the error in the heating value being 4 per cent). At an altitude of 10 000 feet, the error introduced in this way is more than 100 per cent. Gas regulations should be written so that the value assigned to the standard used, whether it be a candle, a pentane lamp, or other standard, should be its average value as nearly as practicable, corresponding to the mean barometric pressure of the place where it is used.

If this procedure is adopted, the Bureau of Standards would, after making some further investigations on the variation of candlepower with barometric pressure, certify a pentane lamp for the particular altitude at which it was to be used, in addition to giving its sea-level candlepower.

In order to show clearly the effect of reduced barometric pressure on the candlepower and heating values found for gas by existing methods of testing, we have prepared Table II. In the first column is given the actual candlepower of a gas flame if tested by comparison with a pentane lamp at various altitudes, and in each case reported to be 16 candles. In the fourth column the corresponding heating values are given, supposing the gas always such as to give 600 Btu at 30 inches barometric pressure, and hence by the present method of calculating the result the heating value would be reported as 600 in each case.

TABLE II
Effect of Altitude in Gas Rating
Actual Quality of Gas Rated 600 Btu and 16 cp

Actual candlepower ⁷	Altitude (feet)	Barometer (inches)	Actual heat value (Btu)
7.6	10 000	20.70	414
8.4	9000	21.47	429
9.1	8000	22.28	445
10.0	7000	23.11	462
10.9	6000	23.98	480
11.6	5000	24.91	498
12.4	4000	25.81	516
13.3	3000	26.78	536
14.2	2000	27.78	556
15.0	1000	28.82	576
15.4	⁸ 500	29.35	587
15.9	Sea level	29.90	598
16.0	— 100	30.00	600

⁷ In calculating actual candlepower and actual heating value no account is taken of fact that gas in mains is above atmospheric pressure.

⁸ The average altitude of 45 of the largest cities of the United States is about 500 feet.

In what has been said above no criticism is intended of any gas company for following the current practice of reducing calorimetric and photometric measurements. But it is believed that

this practice should be abandoned as soon as practicable and, as suggested, the gas tested under the same conditions as those under which it is sold.

11. CANDLEPOWER TEST BURNER

It is customary to refer to gas as having a certain candlepower, without any statement as to the method of the test. However, gas has no constant luminous value corresponding to the heating power of the gas. The quantity of light given out in burning the gas is largely dependent upon the character of the burner; whereas the heat given out in burning the gas is the same in any burner, assuming complete combustion. From the above facts it is evident that a candlepower specification should not be made without stating what burner is to be used.

In choosing a candlepower-test burner, the following facts should be taken into account:

First. The primary object of a candlepower requirement should be to afford protection to users of open-flame burner.

Second. The best way in which the usefulness of the gas for open-flame lights can be obtained is by testing the gas in an open-flame burner.

Third. The open-flame candlepower of a gas may be higher or lower than the Argand candlepower, according to the kind of gas; hence the candlepower required should be varied according to which test burner is used, and the burner specified. The use of the phrase, "the burner best suited to the gas," or any similar phrase, is indefinite and should be avoided.

On the above basis the Bureau recommends that testing regulations should specify that the candlepower of the gas be measured with an open-flame burner, a different burner, of course, being used for acetylene and Pintsch gas than for ordinary illuminating gas.

12. SULPHUR, AMMONIA, AND HYDROGEN SULPHIDE

The reasons for the limits which are proposed for sulphur, ammonia, and hydrogen sulphide have been discussed in the first edition of Circular No. 32. There is nothing in those proposals which seems to require explanation at this time except the reason

for the retention of the ammonia limit in the law and the basis upon which different values have been set as to amount of ammonia and sulphur allowed in coal gas and water gas.

The retention of the ammonia limit in the law has been criticized on the ground that it is unnecessary; that gas companies will remove this impurity because it is too valuable to lose. This is true of probably over 90 per cent of the gas companies, and these need not be worried by the retention of the limit, but even at the present time some companies do not remove the ammonia with sufficient care. It is said that for its own protection a company must remove the ammonia or it will ruin its meters, but if this happens the gas consumers will ultimately bear the expense. It is therefore best to retain the limit even though it is probable that without it the results would be the same. If it is retained, there is no question as to what the company is expected to do.

With the fuel supplies which are available at the present time coal gas can not be made as low in ammonia and sulphur compounds, other than hydrogen sulphide, as can water gas. There is no difficulty in maintaining the ammonia and sulphur in water gas below 5 and 20 grains per 100 cubic feet, respectively; and the public should be assured by proper regulations that these limits will be observed. In the case of most coal-gas plants the same limits would be possible for ammonia as are used for water gas, and in these plants a 5-grain limit would be proper; but in a few coal-gas plants it may be necessary to permit as much as 10 grains. In order to provide for these cases we have set the general limit for ammonia at 10 grains.

The sulphur limitation in coal-gas manufacture becomes in effect a limitation upon the quality of coal purchased. It is desirable, therefore, that the limits set be not unduly severe, lest a coal which otherwise would be very economical for gas making may be excluded, but some limit should be in force to exclude an unnecessarily high sulphur gas. The public has a right to demand and should be assured of the lowest quantity of sulphur and ammonia practicable. To accomplish this without placing undue burden upon coal-gas makers the different standards for coal gas and water gas have been set.

13. COMPOSITION OF GAS

From the standpoint of the consumer it is immaterial what the chemical composition of the gas is, so long as it contains no injurious constituents and possesses the specified heating value and candlepower. Hence, no specification as to the quantity of oxygen, nitrogen, and carbon dioxide should be made. The limitation of carbon monoxide, which is sometimes urged, is based upon the fact that it is poisonous, being the only poisonous constituent of illuminating gas. But inasmuch as illuminating gas can not be made commercially without containing a considerable percentage of carbon monoxide, it is impracticable to set limits upon it unless the manufacture of water gas is to be forbidden, which seems economically impossible. Hence, the Bureau recommends that, instead of attempting to restrict the quantity of CO in the gas, that its danger be minimized by educating the public in the use of gas and gas appliances, and that gas appliances be improved and their use and installation be studied with a view to securing perfect combustion, good ventilation, and the minimum of danger.

14. PRESSURE OF GAS

The great diversity of opinion on the subject of regulations affecting the pressure of gas supply has made generalizations on this subject most difficult. However, the recommendations which were made by the Bureau as to the minimum and maximum pressures and allowable variations were very conservative, as shown by evidence which has been presented since the publication of the circular. For later editions the investigation and discussion will be extended along several lines, particularly those suggested in the report made by W. A. Baehr to the New York Public Service Commission of the first district.

15. METER TESTING REQUIREMENTS

There is little to add at present to the discussion of meter-setting requirements in the first edition of Circular No. 32. The question of frequency of reinspection of meters is always an open one; but since publication of the circular no evidence has been submitted to the Bureau to indicate conditions warranting a change from the former recommendation.

The Bureau of Standards is considering all of the subjects discussed above in a very conservative and careful manner. We are calling attention to the facts as we understand them and are inviting discussion and a comparison of experiences. We are taking account not only of experience in our own laboratories but in other laboratories as well. The Bureau invites written expressions of opinion and experience from anyone interested, with the hope that a judicial and open-minded consideration of such suggestions and of all the evidence may result in a satisfactory decision as to what we shall recommend. Our recommendations are, of course, not binding anywhere, but they are made as carefully as though they were.

We wish to express our thanks to the officers of the American Gas Institute for this opportunity to bring before you some of the results of our study of the subject of the technical specifications for the quality of gas and gas service, and also for the cordial cooperation and assistance given this work by many of your members. It is our aim to be of service to the industry as well as to the public, and we welcome suggestions and criticisms which are intended to assist us in reaching correct conclusions.

WASHINGTON, January 10, 1913.



CIRCULARS.

- No. 1. Verification of Standards and Measuring Instruments.
- No. 2. Verification of Metal Tapes.
- No. 3. Verification of Standards of Mass.
- No. 4. Verification of Standards of Capacity.
- No. 5. Testing of Clinical Thermometers.
- No. 6. Electric, Magnetic, and Photometric Testing.
- No. 7. Pyrometer Testing and Heat Measurements.
- No. 8. Testing of Thermometers.
- No. 9. Testing of Glass Volumetric Apparatus.
- No. 10. Legal Weights (in pounds) per Bushel of Various Commodities.
- No. 11. The Standardization of Bomb Calorimeters.
- No. 12. Verification of Polariscope Apparatus.
- No. 13. Standard Specifications for the Purchase of Incandescent Lamps.
- No. 14. Samples of Analyzed Irons and Steels—Methods of Analysis.
- No. 15. A Proposed International Unit of Light.
- No. 16. The Testing of Hydrometers.
- No. 17. Magnetic Testing.
- No. 18. Standard Gauge for Sheet and Plate Iron and Steel.
- No. 19. Standard Density and Volumetric Tables.
- No. 20. Testing of Electrical Measuring Instruments.
- No. 21. Precision Measurements of Resistance and Electromotive Force.
- No. 22. Standard Specifications for Transformers, Oil-immersed, Self-cooled, 60-cycle, 2,200 Volts.
- No. 23. Standardization of Electrical Practice in Mines.
- No. 24. Publications of the Bureau of Standards.
- No. 25. Standard Analyzed Samples—General Information.
- No. 26. Analyzed Iron and Manganese Ores—Methods of Analysis.
- No. 27. The Testing and Properties of Optical Instruments.
- No. 28. The Determination of the Optical Properties of Materials.
- No. 29. Announcement of a Change in the Value of the International Volt.
- No. 30. Lime: Its Properties and Uses.
- No. 31. Copper Wire Tables.
- No. 32. State and Municipal Regulations for the Quality, Distribution, and Testing of Illuminating Gas.
- No. 33. United States Government Specification for Portland Cement.
- No. 34. The Relation of the Horsepower to the Kilowatt.
- No. 35. Melting Points of Chemical Elements.
- No. 36. The Testing and Properties of Electrical Condensers.
- No. 37. Electric Wire and Cable Terminology.
- No. 38. The Testing of Mechanical Rubber Goods.
- No. 39. Specifications for and Measurement of Standard Sieves.
- No. 40. Sodium Oxalate as a Standard in Volumetric Analysis.

